CHAPTER 4.

Lead exposures in the human environment

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4.1. Introduction

Humans consume lead by inhaling air. drinking beverages. eating food and ingesting dust. The natural source of this lead is primarily soil. The anthropogenic sources are lead in gasoline. lead in fossil fuels and a number of industrial lead products and processes. These sources have made lead ubiquitous in the human environment. The task of sorting out the primary sources of lead in any particular environmental component has become a difficult chore. Nevertheless. it is the purpose of this chapter to describe not only the total exposure of humans to environmental lead. but to determine. to the best of our knowledge, the sources of lead that contribute to this exposure. The total exposure. in this report. is the total amount of lead consumed by ingestion and inhalation.

By excluding sources of lead that originate from choice or circumstance. a baseline level of potential human exposure can be defined for a normal individual. Such an individual would eat a typical diet and live in a nonurban community remote from industrial sources of lead in a house without lead-based paints. This baseline exposure is deemed to be unavoidable by any reasonable means. and includes lead in small amounts from all major sources depicted in Fig. 4.1. Beyond this level. additive exposure factors can be determined for other environments (e.g. urban. occupational and smelter communities). for certain habits and activities (e.g. pica. smoking. drinking and hobbies). and for variations due to age. sex or socioeconomic status. It will become clear in the final analysis that exposure beyond the baseline level is due mostly to the increased concentrations of lead in ingested dusts. rather than to the inhalation of air.
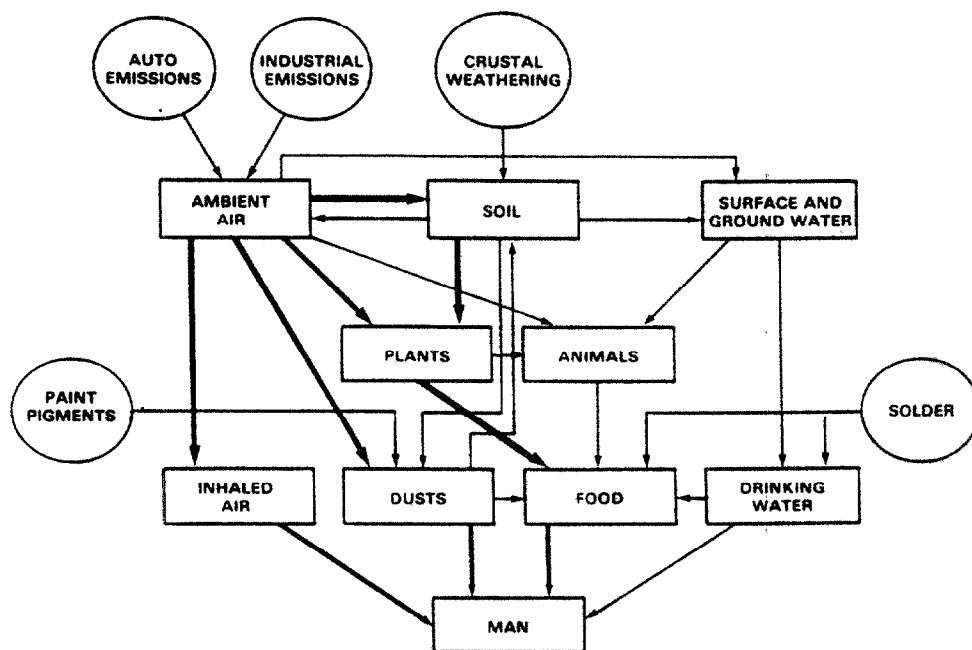
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Fig. 4.1. The major sources of lead in the human environment are automobile and industrial emissions to the atmosphere. crustal weathering of natural lead. pigment lead in printed materials and painted surfaces and solder.

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4.2. Lead in the human environment

Ambient airborne lead concentrations influence human exposure through direct inhalation of lead-containing particles and through ingestion of atmospheric lead that has been deposited onto surfaces. Although an abundance of data on airborne lead is now available, our understanding of the pathways to human exposure is restricted by the condition that most ambient measurements were taken independently of studies of the concentrations of lead in man or in components of his food chain. Ambient air concentrations in the United States are comparable to other industrialized nations. In remote regions of the world. air concentrations are two or three orders of magnitude lower. lending credence to discussions below of the concentrations of natural lead in the atmosphere.

4.2.1. Lead in air

The wide range of concentrations is apparent from Table 4.1. which summarizes data obtained from numerous independent measurements. Concentrations vary from $0.000076 \ \mu g/m^3$ in remote areas to over $10 \ \mu g/m^3$ near sources such as smelters. Some of

report lead levels in teeth and bones of contemporary populations to be elevated 100-fold over levels in ancient Nubians buried before 750 A.D. In some studies, such as the report by Barry and Connolly (1981) of excessive lead concentrations in buried medieval English skeletons, there is the distinct possibility that the lead was absorbed into the skeletons from the surrounding soil.

The remote area concentrations reported in Table 4.1 do not necessarily reflect the true natural preindustrial lead. Murozumi et al. (1969) and Ng and Patterson (1981) have measured a 200-fold increase over the past 3000 years in the lead content of Greenland snow. This lead probably originated in populated mid-latitude regions, and was transported over thousands of kilometers through the atmosphere to the Arctic. It is likely that all of the concentrations in Table 4.1, including values for remote areas, have been influenced by anthropogenic lead emissions.

Although there are no direct measurements of prehistoric natural concentrations of lead in air, air lead concentrations that existed in prehistoric times may be inferred from available data. Table 4.1 lists several values for remote areas of the world, the lowest of which is $0.000076 \ \mu g/m^3$ at the South Pole (Maenhaut et al., 1979). Two other reports show comparable values: $0.00017 \ \mu g/m^3$ at Eniwetok in the Pacific Ocean (Settle and Patterson, 1982) and $0.00015 \ \mu g/m^3$ at Dye 3 in Greenland (Davidson et al., 1981a). Since each of these studies reported some anthropogenic influence, it may be assumed that natural lead concentrations are somewhat lower than these measured values.

Another approach to determining natural concentrations is to estimate global emissions from natural sources. Nriagu (1979) estimated emissions at 24.5×10^6 kg/year, whereas Settle and Patterson (1980) estimated a lower value of 2×10^6 kg/year. An average tropospheric volume, to which surface generated particles are generally confined, is about $2.55 \times 10^{18} \ m^3$. Assuming a residence time of 10 days, natural lead emissions during this time would be $6.7 \times 10^{14} \ \mu g$. The air concentrations would be $0.000263 \ \mu g/m^3$ using the values of Nriagu (1979) or $0.0000214 \ \mu g/m^3$ using the data of Settle and Patterson (1980). It seems likely that the concentration of natural lead in the atmosphere is between 0.00002 and $0.00007 \ \mu g/m^3$.

The effects of airborne lead on human health and welfare depend in part upon the sizes of the lead-containing particles. Large particles are removed relatively quickly from the atmosphere by dry and wet deposition processes. Particles with diameter smaller than a few micrometers tend to remain airborne for days or weeks and are thus capable of long range transport. Air lead concentrations usually decrease with vertical and horizontal distance from emission sources, and are generally lower indoors than outdoors. Because people spend much of their time indoors, ambient air data may not accurately indicate actual exposure to airborne lead. In nearly all cases, the indoor concentration is substantially lower than the corresponding value outdoors. Overall, the data suggest indoor/outdoor ratios of 0.6 to 0.8 are typical for airborne lead in houses without air conditioning

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(Halpern. 1978). Ratios in air conditioned houses are expected to be in the range of 0.3 to 0.5 (Yocum, 1982).

4.2.2. Lead in soil

Much of the lead in the atmosphere is transferred to terrestrial surfaces. where it is eventually passed to the upper layer of the soil surface. Shacklette et al. (1971) sampled soils at a depth of 20 cm to determine the elemental composition of soil materials derived from the earth's crust, without atmospheric influence. The range of values probably represents natural levels of lead in soil, although there may have been some contamination with anthropogenic lead during collection and handling. The arithmetic mean of 20 $\mu g/g$ and geometric mean of 16 $\mu g/g$ reflect the fact that most of the 863 samples were below 30 $\mu g/g$ at this depth. McKeague and Wolynetz (1980) found the same arithmetic mean (20 $\mu g/g$) for 53 uncultivated Canadian soils.

Atmospheric lead is retained in the upper few centimeters of undisturbed soil. especially soils with at least 5% organic matter and a pH of 5 or above. Because lead is immobilized by the organic component of soil, the concentration of anthropogenic lead in the upper layer is determined by the flux of atmospheric lead at the soil surface. Near emission sources. this flux is largely by dry deposition. which drops off exponentially with increasing distance from the source. Roadside soils may contain atmospheric lead from 30 to 2000 $\mu g/g$ in excess of natural levels within 25 meters of the roadbed. all of which is in the upper layer of the soil profile (Rolfe and Jennett. 1975).

Near primary and secondary smelters. lead in soil also decreases exponentially. but the zone of contamination extends to 5–10 km from the smelter complex. Soil lead contamination varies with the smelter emission rate. length of time the smelter has been in operation. prevailing wind speed and direction. regional climatic conditions. and local topography (Roberts. 1975). Little and Martin (1972) observed decreases from 125 to 10 $\mu g/g$ in a 6 km zone around a smelting complex in Great Britain: all of the excess lead was in the upper 6 cm of the soil profile. Roberts (1975) reported soil lead between 15 000 and 20 000 $\mu g/g$ near a smelter in Toronto. Kerin (1975) found 5 000 to 9 000 $\mu g/g$ adjacent to a Yugoslavian smelter: the contamination zone was 7 km in radius. Ragaini et al. (1977) observed 7 900 $\mu g/g$ near a smelter in Kellogg, Idaho: they also observed a 100-fold decrease at a depth of 20 cm in the soil profile. Palmer and Kucera (1980) observed soil lead in excess of 60 000 $\mu g/g$ near two smelters in Missouri. decreasing to 10 $\mu g/g$ at 10 km from the smelter.

Urban soils may be contaminated from a variety of atmospheric and nonatmospheric sources. The major sources of soil lead seem to be paint chips from older houses and deposition from nearby highways. Lead in soil adjacent to a house decreases with distance from the house; this may be due to paint chips or to dust of atmospheric origin washing from the rooftop (Wheeler and Rolfe. 1979).

TABLE 4.2
Summary of soil lead concentrations [a]

	Natural lead	Atmospheric lead		Total lead	
		Rural	Urban	Rural	Urban
Total soil	8–25	3	50–150	8–30	150–300
Primary minerals	8–25	–	–	8–25	8–25
Humic substances [b]	20	60	2000	80	2000
Soil moisture	0.0005	0.0005	0.0150	0.001	0.0155

a. Units are μg Pb/g.
b. Assumes 5% organic matter, pH 5.0; may also include lead in Fe-Mn oxide films.

Except near roadsides and smelters, only a few μg of atmospheric lead have been added to each gram of soil. Several studies indicate that this lead is available to plants through the small amounts (about 0.01 μg/g) that are dissolved in soil moisture. About 50–75% of the lead in soil moisture is of atmospheric origin (Shirahata et al., 1980; Patterson, 1983). This distribution between natural and anthropogenic lead in soil moisture represents the initial baseline contamination of lead in food crops. A breakdown of the types of lead in soil may be found in Table 4.2.

4.2.3. Lead in food crops

On the surfaces of vegetation, lead is mostly of atmospheric origin, while internal plant tissues contain a mixture of atmospheric and soil lead. As with soils, lead on vegetation surfaces decreases exponentially with distance away from roadsides and smelters (Cannon and Bowles, 1962). Plant surfaces have been used as indicators of lead pollution (Ruhling and Tyler, 1969; Ratcliffe, 1975; Pilegaard, 1978; Garty and Fuchs, 1982; Tanaka and Ichikuni, 1982). These studies all show that lead on the surface of leaves and bark is proportional to traffic density and distance from the highway or, more specifically, to air lead concentration and particle size distribution. Other factors, such as surface roughness, wind direction and wind speed may be important.

In a study to determine the background concentrations of lead and other metals in agricultural crops, the U.S. Food and Drug Administration (Wolnik et al., 1983), in cooperation with the U.S. Department of Agriculture and the U.S. Environmental Protection Agency, analyzed over 1500 samples of the most common crops taken from a cross section of geographic locations. Collection sites were remote from mobile or stationary sources of lead. Soil lead concentrations were within the normal range (8–25 μg/g) of U.S. soils. Extreme care was taken to avoid contamination during collection, transportation and analysis. The concentrations of lead in crops found by Wolnik et al. (1983) are shown

as 'Total' concentrations in Table 4.3. The breakdown by source of lead is discussed below. These basic crops probably represent the lowest concentrations of lead in food generally available to Americans. There are several reasons why the lead concentrations in crops harvested by normal farming methods might be somewhat higher: some crops are grown closer to highways and stationary sources of lead than those sampled by Wolnik et al. (1983), some harvest techniques used by farmers might add more lead to the crop than did Wolnik et al., and some crops are grown on soils significantly higher in lead than those of the Wolnik et al. study because of a history of fertilizer additions or sludge applications.

To estimate the distribution of natural and atmospheric lead in food crops (Table 4.3), it is necessary to recognize that some crops of the Wolnik et al. study have no lead directly from atmospheric deposition, in which case all lead comes through soil moisture that contains both natural and atmospheric lead. The lowest concentrations of lead are found in those crops where the edible portion grows above ground and is protected from atmospheric deposition (sweet corn and tomatoes). Below-ground crops are also protected from atmospheric deposition but have slightly higher concentrations of lead,

TABLE 4.3
Background lead in basic food crops and meats [a]

Crop	Lead from soil	Lead from atmosphere	Total lead [b]
Wheat	0.003	0.034	0.037
Potatoes	0.009	–	0.009
Field corn	0.003	0.019	0.022 [c]
Sweet corn	0.003	-	0.003
Soybeans	0.042	-	0.042
Peanuts	0.01	–	0.01
Onions	0.0046	–	0.0046 [c]
Rice	0.003	0.004	0.007 [c]
Carrots	0.009	–	0.009 [c]
Tomatoes	0.002	--	0.002 [c]
Spinach	0.003	0.042	0.045 [c]
Lettuce	0.003	0.010	0.013
Beef (muscle)	0.0022	0.02	0.02 [d]
Pork (muscle)	0.0022	0.06	0.06 [d]

a.   Units are μg Pb/g fresh weight.
b.   Except as indicated, data are from Wolnik et al. (1983).
c.   Preliminary data provided by the Elemental Analysis Research Center. Food and Drug Administration. Cincinnati. OH.
d.   Data from Penumarthy et al. (1980).

partly because lead accumulates in the roots of plants (potatoes, onions and carrots). Leafy above-ground plants (lettuce. spinach and wheat) have even higher lead concentrations. presumably because of exposure to atmospheric lead. The assumption that can be made here is that. in the absence of atmospheric deposition, exposed above-ground plant parts would have lead concentrations similar to protected above-ground parts. and lower than below-ground parts.

The data on these ten crops suggest that root vegetables have lead concentrations between 0.0046 and 0.009 μg/g, which is all derived from soil lead that presumably is half natural and half anthropogenic. Above-ground parts not exposed to significant amounts of atmospheric deposition (sweet corn and tomatoes) have less lead internally. also equally divided between natural and atmospheric lead. If it is assumed that this same concentration is the internal concentration for above-ground parts for other plants. it is apparent that five crops have atmospheric deposition in proportion to surface area and estimated duration of exposure. A conservative estimate of a deposition rate of only 0.00004 μg/cm^2/day in rural environments could account for these amounts of atmospheric lead. This is half the deposition rate for an upfacing surface in a remote area where the air lead concentration was 0.01–0.025 μg/m^3 (Elias and Davidson. 1980).

Root parts and protected above-ground parts of edible crops contain natural lead and atmospheric lead. both derived from the soil. For exposed above-ground parts. any lead in excess of the average found on unexposed above-ground parts is considered to be the result of direct atmospheric deposition. There is no explanation for the anomalously high lead concentration in soybeans. Soybeans grow inside a sheath and should have an internal lead concentration similar to corn.

Lead in forage was found to exceed 950 μg/g within 25 m of roadsides with 24 000–38 000 vehicles/day (Graham and Kalman. 1974). At lesser traffic densities. 50–200 μg/g were found. Other reports have observed 20–660 μg/g with the same relationship to traffic density and distance from the road (see review by Graham and Kalman. 1974). A more recent study by Crump and Barlow (1982) showed that the accumulation of lead in forage is directly related to the deposition rate. which varied seasonally according to traffic density and vegetational growth cycles.

4.2.4. Lead in natural waters

Lead occurs in untreated water in either dissolved or particulate form. Because atmospheric lead in rain or snow is retained by soil. there is little correlation between lead in precipitation and lead in streams that drain terrestrial watersheds. Rather. the important factors seem to be the chemistry of the stream (pH and hardness) and the volume of the stream flow. For ground water. chemistry is also important. as is the geochemical composition of the water-bearing bedrock.

The initial concentration of lead in this water depends largely on the source of the untreated water. Of the year-round housing units in the United States. 84% receive their

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drinking water from a municipal or private supply of chemically treated surface or ground water. The second largest source is privately owned wells (U.S. Bureau of the Census, 1982). In some communities, the purchase of untreated bottled drinking water is a common practice.

Durum et al. (1971) reported a range of 1–55 μg/l in 749 surface water samples in the United States. Very few samples were above 50 μg/l, and the average was 3.9 μg/l. Chow (1978) reviewed other reports with mean values between 3 and 4 μg/l. The National Academy of Sciences (1980) reported a mean of 4 μg/l with a range from below detection to 890 μg/l. Concentrations of 100 μg/l were found near sites of sewage treatment, urban runoff and industrial waste disposal.

The municipal and private wells that account for a large percentage of the drinking water supply typically have a neutral pH and a hardness somewhat higher than surface water. Lead concentrations in ground water do not appear to be influenced by acid rain, surface runoff or atmospheric deposition. Rather, the primary determinant of lead concentration is the geochemical makeup of the bedrock that is the source of the water supply. Ground water typically ranges from 1 to 100 μg Pb/l (National Academy of Sciences, 1980).

Whether from surface or ground water supplies, municipal waters undergo extensive chemical treatment prior to release to the distribution system. Most of the original lead is removed during flocculation and sedimentation in the normal processing of water through a water treatment facility. On the other hand, chemical treatment to soften water increases the solubility of lead and enhances the possibility that lead will be leached from metal surfaces as it passes through the distribution system.

For samples taken at the household tap, lead concentrations are usually higher in the initial volume (first daily flush) than after the tap has been running for some time. Water standing in the pipes for several hours is intermediate between these two concentrations (Worth et al., 1981; Sharrett et al., 1982). Common plumbing materials are galvanized and copper pipe and lead solder is usually used to seal the joints of copper pipes. Lead pipes are seldom in service in the United States, except in the northeastern states (Worth et al., 1981).

The age of the plumbing is an important factor. New copper pipes with lead solder exposed on the inner surface of the joints produce the highest amount of lead in standing water. After several years, this lead is leached away and copper pipes subsequently have less lead in standing water than galvanized pipes. The pH of the water is also important: the acidic water of some eastern United States localities can increase the leaching rate of lead from lead pipes or lead solder joints and prevent the build-up of a protective coating of calcium carbonate plaque.

Table 4.4 summarizes the contribution of atmospheric lead to natural waters and drinking water supplies. In this determination, the maximum reported value for natural lead (0.02 μg/l) was used, all additional lead in untreated water is considered to be of

TABLE 4.4

Summary of lead in drinking water supplies [a]

TABLE 4.5

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	Lead from soil	Atmospheric lead	Non-atmospheric anthropogenic lead	Total lead
Untreated				
Lakes	15	10	–	25
Rivers	15	15	–	30
Streams	2.5	2.5	–	5
Ground water	3	–	–	3
Treated				
Surface water	2.5	1.5	4	8
Ground water	0.45	–	7.5	8

a. Units are μg Pb/l.

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atmospheric origin. It is assumed that treatment removes 85% of the original lead, and that any lead added during distribution is anthropogenic lead from solder or pipes.

The use of treated water in the preparation of food can be a significant source of lead in the human diet. However, there are many uncertainties in determining this contribution. Water used in food processing may be from a municipal supply or a private well. This water may be used merely to wash the food, as with fruits and vegetables, or as an actual ingredient. Water lead may remain on food that is partially or entirely dehydrated during processing (e.g. pasta). Water used for packing or canning may be used with the meal or drained prior to preparation. Considering both drinking water and food preparation, a significant amount of lead can be consumed by humans from treated water, but only a small fraction of this lead is of atmospheric origin.

Lead concentrations in environmental media that are in the pathway to human consumption are summarized in Table 4.5. These values are estimates derived from the preceding discussions. In each category, a single value is given, rather than a range, in order to facilitate further estimates of actual human consumption. This use of a single value is not meant to imply a high degree of certainty in its determination or homogeneity within the human population. The units for water are converted from μg/l as in Table 4.4 to μg/g to facilitate the discussions of dietary consumption of water and beverages. The rationale for Table 4.5 is taken from the discussions of Section 4.2, which are summarized in the next paragraph.

Because concentrations of natural lead are generally three to four orders of magnitude lower than anthropogenic lead in ambient rural or urban air, all atmospheric contributions of lead are considered to be of anthropogenic origin. Natural soil lead typically

TABLE 4.5
Summary of environmental concentrations of lead [a]

	Natural lead	Atmospheric lead	Total lead
Urban air (μg/m^3)	0.00005	0.8	0.8
Rural air (μg/m^3)	0.00005	0.2	0.2
Soil total (μg/g)	8–25	3.0	15.0
Food crops (μg/g)	0.0078	0.022	0.03
Surface water (μg/g) [b]	0.00002	0.005	0.005
Ground water (μg/g) [b]	0.003	–	0.003

a. The basis for use of a single value is described in Section 4.2.4.
b. Note change in units from Table 4.4.

ranges from 10 to 30 μg/g, but much of this is tightly bound within the crystalline matrix of soil minerals at normal soil pHs of 4 to 8. Lead in the organic fraction of soil is partly natural and partly atmospheric. The fraction derived from fertilizer is considered to be minimal. In the available fraction of undisturbed rural and remote soils, the ratio of natural to atmospheric lead is about 1:1, perhaps as high as 1:3. This ratio persists in soil moisture and in internal plant tissues (Patterson, 1983). Thus, some of the internal lead in crops is of anthropogenic origin, and some is natural. Lead in untreated surface water is 99% anthropogenic, presumably atmospheric except near municipal waste outfalls. It is possible that 75% of this lead is removed during treatment. Lead in untreated ground water is probably all natural.

In tracking air lead through pathways to human exposure, it is necessary to distinguish between lead of indirect atmospheric origin that has passed through the soil, and atmospheric lead that has deposited directly on crops or water. Because atmospheric lead will remain in the soil for many decades, this indirect source is insensitive to projected changes in atmospheric lead concentrations.

4.3. Human consumption of environmental lead

The preceding section discussed ambient concentrations of lead in the environment, focusing on levels in the air, soil, food crops and water. In this section, environmental lead concentrations are examined from the perspective of actual or potential human consumption. Initially, a baseline scenario is described for an individual with a minimum amount of daily lead consumption. This person would live and work in a nonurban environment, eat a normal diet of food taken from a typical grocery shelf, and would have no habits or activities that would tend to increase lead exposure. Lead exposure at the baseline level is

considered unavoidable without further reductions of lead in the atmosphere or in canned foods. Most of the baseline lead is of anthropogenic origin, although a portion is natural.

4.3.1. Baseline human consumption

This summary of lead in the human environment includes an analysis of anthropogenic and natural lead in the diet (food, water and beverages), in inhaled air and in ingested dust. The dietary information is taken from three sources: (a) the total diet food list of Pennington (1983), which lists the amounts of food consumed (201 adult food types, 30 baby food types) by 8 age/sex groups, (b) the lead data of the FDA Market Basket Study (U.S. FDA, 1984), which reports lead concentrations in the 231 food list categories by geographic area (only the 201 adult food categories were available for this report; and (c) the food crop data of the Wolnik et al. (1983) study described in Section 4.2.

The strategy for this exposure analysis is to combine the food list items of the Pennington (1983) diet study into categories originating from food crops or meats shown in Table 4.3. The meat category was divided into meats and dairy products, and the food crop category was separated into canned and soft packaged foods. Of the 201 adult food categories, 171 were placed wholly within one of the four summary categories of food or five categories of beverages, while 30 categories (e.g. hamburger sandwiches) were split between two or more summary categories, depending on the estimated components of the food item. Because data were not available for the 30 categories of baby food items, the youngest age category is not reported here, and only the seven older age/sex groups are

TABLE 4.6

Total food and beverages consumed daily by food category and age/sex group [a]

	Child (2 yrs)	14–16 years		25–30 years		60–65 years	
		Female	Male	Female	Male	Female	Male
Dairy products	379	411	643	247	356	211	275
Meat products	118	177	261	183	308	161	233
Food crops	290	381	522	383	509	434	511
Canned food	65	83	96	77	87	85	102
Canned juices	54	28	30	28	27	17	12
Frozen juices	65	53	75	66	73	72	61
Soda	70	232	274	228	316	78	85
Canned beer	–	–	16	35	299	9	99
Water [b]	434	587	733	912	1059	1166	1250
Total	1475	1952	2650	2159	3034	2233	2628

a. Data are summarized from Pennington (1983). Units are µg Pb/day.
b. Includes coffee, tea and powdered beverages.

TABLE 4.7
Total lead consumption in food. water and beverages. by age/sex group [a]

	Child (2 yrs)	14–16 years		25–30 years		60–65 years	
		Female	Male	Female	Male	Female	Male
Dairy products	2.4	3.3	5.1	2.3	3.3	1.9	2.5
Meat products	3.0	4.5	7.2	4.7	7.1	3.6	5.2
Food crops	6.0	9.5	13.7	9.2	13.2	9.0	11.2
Canned food	7.5	8.0	12.1	9.1	12.2	11.5	14.9
Canned juices	2.2	1.0	1.1	1.1	1.0	0.7	0.5
Frozen juices	0.6	0.6	0.8	0.7	0.8	0.8	0.6
Soda	1.3	4.3	5.5	3.7	5.2	1.6	1.6
Canned beer	–	–	0.2	0.4	3.3	0.1	1.1
Water [b]	2.8	3.6	4.7	4.8	8.6	5.7	7.2
Total	25.8	34.8	50.4	36.0	54.7	34.9	44.8

a. Units are μg Pb/day.
b. Includes coffee. tea and powdered beverages.

shown. Table 4.6 shows the total amount of food consumed by the seven age/sex groups in the nine food/beverage categories.

The lead consumed in food and beverages was determined by multiplying the mean lead concentration for each of the 201 food types by the amount consumed by each age/sex group. The mean lead concentration was an average of four values reported from four geographic locations (FDA. 1984). The data are shown in Table 4.7.

From Tables 4.6 and 4.7. an averaged weighted lead concentration was determined taking the mean of the seven ratios of lead consumed/food consumed. This value is shown as the total lead concentration in Table 4.8 for the nine summary food and beverage categories. This total lead concentration was broken down into atmospheric lead. solder lead, and a miscellaneous category of lead consisting of natural lead, indirect atmospheric lead in soil. pigment lead, and atmospheric/solder lead not otherwise accounted for in the first two columns.

The value of atmospheric lead in Table 4.8 was derived from the discussion in Section 4.2. in particular the data of Tables 4.3 and 4.4. Only the minimum contribution of atmospheric lead was assumed for seven of the nine food and beverage categories because no justification could be determined for the further addition of atmospheric lead during food processing. For food crops and canned foods, a small additional amount of atmospheric lead was added to account for the increase in lead concentration during food processing. Data from the National Food Processors Association, provided to the Food and Drug Administration, support this assumption.

TABLE 4.8
Weighted lead concentrations by source of lead [a]

	Total lead concn.	Atmospheric lead	Lead from solder	Other types of lead
Dairy products	0.0085	0.007	–	0.0015
Meat products	0.025	0.02	0.002	0.003
Food crops	0.026	0.016	–	0.01
Canned foods	0.125	0.016	0.1	0.009
Canned juices	0.040	0.0015	0.036	0.0025
Frozen juices	0.011	0.0015	0.007	0.0025
Soda	0.018	0.0015	0.014	0.0025
Canned beer	0.017	0.0015	0.007	0.0025
Water [b]	0.007	0.0015	0.003	0.0025

a. Total lead concentration was determined as an average of the 7 age/sex groups of the lead consumed in each food category. Units are μg Pb/g.

b. Includes coffee. tea and powdered drinks.

In all. 60–90% of the total lead in food and beverages can be accounted for by assuming a minimum contribution of atmospheric lead and a reasonable amount of solder lead. Of the remaining 10–40%, probably less than 5% derives from the natural and indirect atmospheric lead of soil.

For each of the nine food and beverage categories. a mean daily consumption of lead is shown in Table 4.9. This is a mean of the seven age/sex categories of Table 4.7. From this. the fraction that is identified as atmospheric. solder. or 'other' lead in Table 4.8 is used to determine the daily lead consumption by source in Table 4.9. These data show that about 40% of the lead consumed in food and beverages is of atmospheric origin, 40% derives from solder. and 20% is natural. indirect atmospheric or pigment lead or atmospheric/solder lead that cannot be clearly designated as such. Although the amounts for each age/sex group differ. the percentages are roughly the same.

Atmospheric lead consumed by inhalation is minimal. The air concentrations in nonurban regions not adjacent to smelters or highways range from 0.05 to 0.15 $\mu g/m^3$. Using a mean value of 0.1 $\mu g/m^3$, an indoor/outdoor ratio of 0.5. and assuming that the average individual stays indoors 18–22 h/day, a mean effective lead concentration in inhaled air is about 0.05 $\mu g/m^3$. If the person works outside. a value of 0.1 $\mu g/m^3$ might be more reasonable. Table 4.10 shows the consumption of atmospheric and natural lead by inhalation. For practical purposes. all of this lead is considered consumed, whether by absorption across lung tissue or ingestion of trapped particles. The fraction exhaled is considered insignificant to the total picture of lead exposure.

TABLE 4.9
Total amount of lead consumed. by source and food category [a]

	Total lead consumed	Atmospheric lead consumed	Lead from solder and other metals	Other types of lead
Dairy products	3.0	2.5	–	0.5
Meat products	5.0	4.0	0.4	0.6
Food crops	10.3	6.3	–	4.0
Canned food	10.8	1.4	8.6	0.8
Canned juices	1.1	0.1	0.9	0.1
Frozen juices	0.7	0.1	0.4	0.2
Soda	3.3	0.3	2.6	0.4
Canned beer	1.0	0.1	0.6	0.3
Water [b]	5.3	1.1	2.3	1.9
Totals	40.5	15.9	15.8	8.8
% of total	100	39.3	39.0	21.7

a. Data are averaged over the 7 age/sex groups. Units are μg Pb/day.
b. Includes coffee. tea. and powdered beverages.

TABLE 4.10
Summary of inhaled air lead exposure

	Adjusted air lead concn. [a] (μg/m³)	Amount inhaled (m³/day)	Total lead exposure (μg/day)	Natural lead (μg/day)	Direct atmospheric lead (μg/day)
Children (2-year-old)	0.05	10	0.5	0.001	0.5
Adult. working inside	0.05	20	1.0	0.002	1.0
Adult. working outside	0.10	20	2.0	0.004	2.0

a. Values adjusted for indoor/outdoor ratio of lead concentrations and for daily time spent outdoors.

To determine the amount of lead consumed with dust. it is necessary to know the amount of dust consumed and the concentration of lead in dust. There is little scientific basis on which to estimate the amounts of dust consumed by children and adults during normal daily activities. A reasonable approach would be to assume a conservative value and treat this value as a guideline that is sensitive to further research. For the purpose of discussion. this estimate has been taken to be 100 mg for 2-year-old children and 20 mg for adults. The lead concentration in dust depends on the source of the dust. In the

R.W. Elias

Lead e>

baseline situation, there would be no large amounts of lead from highways, smelters or lead-based paints. There would also be no secondary exposure to industrial dust of high lead concentration. Dusts can be divided into three categories: household dust, street dust and occupational (nonlead-based) dust. Several studies (Angle and McIntire, 1979; Harrison, 1979) have found that the lead concentration in nonurban households ranges from 50 to 500 μg/g. For the purpose of discussion, a mean value of 300 μg/g is assumed, of which about 10 μg/g would be natural lead. Nonurban street dusts range from 80 to 130 μg/g (Day et al., 1979). A mean value of 90 μg/g is assumed. Dusts from nonlead-related industrial sources brought home by working parents are assumed to have a mean value of 150 μg/g. The following estimate of the human exposure to dust must be treated as a procedural exercise on how one should calculate the contribution of dust to total lead exposure. Rather than a firm estimate of dust lead exposure, it is an estimate that is extremely sensitive to the underlying assumptions. Assuming that a 2-year-old child does indeed consume 100 mg of dust per day, that this dust is of three types having a consumption ratio of 5:4:1 (household: street: industrial) and a lead concentration of 300, 90 and 150 μg/g respectively, then the total lead consumed as dust would be 21 μg/day. These arguments are summarized in Table 4.11, which presents a similar argument for dust lead consumed by adults. In the case of adults, the total amount of dust ingested is taken to be

TABLE 4.11
Baseline estimates of human exposure to dusts

	Dust lead concn. (μg/g)	Dust ingested (g/day)	Dust lead consumed (μg/day)	Source of lead (μg/day)	
				Atmospheric	Other
Child					
Household dusts	300	0.05	15	11.0	4.0
Street dust	90	0.04	4.5	3.4	1.1
Occupational dust	150	0.01	1.5	–	1.5
Totals		0.10	21.0	14.4	6.6
% of total			100	69	31
Adult					
Household dusts	300	0.01	3	2.3	0.7
Street dust	90	–	–	–	–
Occupational dust	150	0.01	1.5	–	1.5
Totals		0.02	4.5	2.3	2.2
% of total			100	57	49

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TABLE 4.12
Summary of the total baseline exposure to lead by age/sex group [a]

	Child (2 yrs)	14-16 years		25-30 years		60-65 years	
		Female	Male	Female	Male	Female	Male
Inhaled air	0.5	1.0	1.0	1.0	1.0	1.0	1.0
Food, water and beverages	25.8	34.8	50.4	36.0	54.7	34.9	44.8
Dust	21.0	4.5	4.5	4.5	4.5	4.5	4.5
Total	47.3	40.3	55.9	41.5	60.2	40.4	50.3
Atmospheric	26.4	18.1	24.2	18.5	25.9	18.1	22.0
Solder	10.1	13.6	19.7	14.0	21.3	13.6	17.5
Average body weight (kg)	13	55	66	65	79	68	79
μg Pb/kg/day	3.6	0.73	0.85	0.64	0.76	0.59	0.64

a. This estimate is extremely sensitive to the amounts of dust consumed and the concentration of lead in this dust. A description of the assumptions used in calculating this table is found in Section 4.3.1, which must be consulted to interpret this table. Units are μg Pb/day.

20 mg/day (50% household, 50% occupational). This would add 4.5 μg/day to the total consumption of lead by adults.

The total consumption of lead by children and adults in a baseline situation is summarized in Table 4.12. For children, the critical environmental component is dust: the estimate of total exposure is extremely sensitive to the assumption that children ingest 100 mg of dust each day. For adults in this baseline situation, air and dust lead are assumed to be the same for each age/sex group, making food and beverage lead the factor that differentiates among the six groups. Furthermore, when body weight is considered the differences become even smaller, ranging from 0.64 to 0.85 μg Pb/kg/day. The striking contrast in this calculation is that children consume 3.6 μg/kg/day, or five times the average adult consumption.

The values derived or assumed in the preceding sections are summarized in Table 4.12. These values only represent consumption, and not absorption of lead by the human body. The approach used here to evaluate potential human exposure is similar to that used by the National Academy of Sciences (1980) and the Nutrition Foundation (1982) in their assessments of the impact of lead in the human environment.

4.3.2. Exposure from nonbaseline sources of lead

Beyond the baseline level of human exposure, additional amounts of lead consumption are largely a matter of circumstance or individual choice. In an urban environment, a

residence near a smelter, a home with lead-based paint, or a family with secondary occupational exposure, the common denominator of increased lead exposure is dust. Specifically, it is the higher lead concentrations in dust more than the increased amount of dust that elevates the lead exposure. In an urban environment, consumption of produce grown in a family garden may increase the daily consumption of lead. Several personal habits, such as smoking, drinking wine and certain hobbies may add to the baseline level of exposure.

Taking the dust-related factors first, the lead concentration in urban household dust increases to 1000 μg Pb/g from the mean values of 300 μg/g reported in the previous section, while street dust increases from 90 to 1500 μg/g (Nriagu, 1978). At 100 mg dust/day, distributed as 50 mg household dust, 40 mg street dust and 10 mg secondary occupational dust, a 2-year-old child would consume 112 μg Pb/day as dust, or 92 μg/day more than the baseline child. The increase by inhalation in this and all other cases would be negligible. When the residence is near a smelter (but no secondary occupational exposure), the street and household dust increases to 25 000 μg Pb/g (Landrigan et al., 1975) giving a total dust exposure of 2250 μg/day for children, or 2230 μg/day more than the baseline estimate.

In a home with interior lead-based paint, the household dust lead increases to about 2000 μg/g, giving an additive exposure increment of 105 μg/day, or 84 μg/day more than baseline. Note that this would be in addition to the urban exposure if the house were in an urban environment.

When one parent works in a lead-related industry, where the industrial dust may reach 100 000 μg/g, the household dust increases to about 2400 μg Pb/g even when sanitary precautions (showers, clothing changes) are taken to prevent lead from being carried home by the worker (Winegar et al., 1977).

It appears that most of the values for lead in dust in nonurban household environments fall in the range of 50 to 500 μg/g. A mean value of 300 μg/g is assumed. The only natural lead in dust would be some fraction of that derived from soil lead. A value of 10 μg/g seems reasonable, since some of the soil lead is of atmospheric origin. Since very little paint lead is included in the baseline estimate, most of the remaining dust lead would be from the atmosphere. Table 4.11 summarizes these estimates of human exposure to dusts for children and adults. It assumes that children ingest about 5 times as much dust as adults, most of the excess being street dusts from sidewalks and playgrounds. Exposure of children to occupational lead would be through contaminated clothing brought home by parents.

Several studies have shown potentially higher lead exposure through the consumption of home-grown produce from family gardens grown on high-lead soils or near sources of atmospheric lead. Kneip (1978) found elevated levels of lead in leafy vegetables, root crops and garden fruits associated qualitatively with traffic density and soil lead. Spittler and Feder (1978) reported a linear correlation between soil lead (100–1650 μg/g) and

lead in leafy or root vegetables. Preer et al. (1980) found a three-fold increase in lead concentrations of leafy vegetables (from 0.3 to 0.9 μg/g corrected to fresh weight) in the soil lead range from 150 to 2200 μg/g. In none of these studies were the lowest soil lead concentrations in the normal range of 10–25 μg/g, nor were any lead concentrations reported for vegetables as low as those of Wolnik et al. (1983).

In family gardens, lead may reach the edible portions of vegetables by deposition of atmospheric lead directly on above-ground plant parts or on soil, or by the flaking of lead-containing paint chips from houses. Traffic density and distance from the road may not be good predictors of soil or vegetable lead concentrations (Preer et al., 1980). Air concentrations and particle size distributions are the important determinants of deposition on soil or vegetation surfaces. Even at relatively high air concentrations (1.5 μg/m^3) and deposition velocity (0.5 cm/s), it is unlikely that surface deposition alone can account for more than 2–5 μg/g lead on the surface of lettuce during a 21-day growing period. It appears that the remainder of the lead in leafy vegetables derives from the soil in the same manner as root vegetables.

Using the conservatively high estimates of air concentration and deposition velocity cited above, a maximum of 1000 μg lead has been added to each cm^2 of the surface of the soil over the past 40 years. With cultivation to a depth of 15 cm, it is not likely that atmospheric lead alone can account for more than a few hundred μg/g of soil in urban gardens. Urban soils with lead concentrations of 500 μg/g or more must certainly have another source of lead. In the absence of a nearby (< 5 km) stationary industrial source, paint chips seem the most likely explanation. Even if the house no longer stands at the site, the lead from paint chips may still be present in the soil.

At the higher soil concentrations, Kneip (1978) reported 0.2–1 μg Pb/g in vegetables. Spittler and Feder (1978) reported 0.9–5.2 μg/g, and Preer et al. (1980) found 0.1–0.9 μg/g (corrected to fresh weight). The studies of Spittler and Feder (1978) and Preer et al. (1980) dealt with soils in the range of 2000 μg/g. These data can be used to calculate a worst case exposure of lead from family gardens. Assuming 0.9 μg/g for the leafy and root vegetables (compared to the 0.01–0.05 μg/g of the Wolnik et al. (1983) study) family gardens could add 120 μg/day to the adult male diet if the 137 g of leafy and root vegetables, sweet corn and potatoes were replaced by family garden products. Comparable values for children and adult females would be 48 and 96 μg/day, respectively. No conclusive data are available for vine vegetables, but the ranges of 0.005 to 0.12 μg/g for tomatoes suggest that the contamination by soil lead is much less for vine vegetables than for leafy or root vegetables.

The Glasgow Duplicate Diet Study (United Kingdom Department of the Environment, 1982) reports that children approximately 13 weeks old living in houses with lead plumbing consume 6–480 μg Pb/day. Water lead levels in the 131 homes studied ranged from less than 50 to over 500 μg/l. Similar conclusions were reached by Sherlock et al. (1982) in a duplicate diet study in Ayr, Scotland.

The highest and most prolonged exposures to lead are found among workers in the lead smelting, refining and manufacturing industries (World Health Organization, 1977). In all work areas, the major route of lead exposure is by inhalation and ingestion of lead-bearing dusts and fumes. Airborne dusts settle out of the air onto food, water, the worker's clothing and other objects, and may be transferred subsequently to the mouth. Therefore, good housekeeping and good ventilation have a major impact on exposure. It has been found that levels might be quite high in one factory and low in another solely because of differences in ventilation, or differences in custodial practices and worker education. The estimate of additional exposure in Table 4.13 is for an 8-hour shift at 10 μg Pb/m^3. Occupational exposure under these conditions is primarily determined by occupational dust consumed. Even tiny amounts (e.g. 10 mg) of dust containing 100 000 μg Pb/g dust can account for 1000 μg/day exposure.

TABLE 4.13
Exposures to lead beyond the baseline level [a]

Source of additional exposure	Child	Adult
Dust-related		
Urban environment [b]	91	7
Residence near smelter [c]	2200	250
Interior lead paint [d]	110	17
Secondary occupational [e]	150	44
Other exposures		
Family gardens [f]	48	120
Occupational [g]	–	1100
Smoking [h]	–	30
Wine consumption [i]	–	100

a. These amounts of lead would be added to the baseline exposure and would vary according to the following parameters. Units are μg Pb/day.
b. Includes lead from household dust (1000 μg Pb/g) and street dust (1500 μg/g). Increment from inhaled air (0.75 μg/m^3) would be negligible.
c. Household and street dusts increase to 25 000 μg/g.
d. Household dust increases to 2000 μg/g.
e. Household dust increases to 2400 μg/g.
f. Assumes soil lead concentration of 2000 μg Pb/g; all fresh vegetables in diet replaced by produce from garden.
g. Occupational dusts assumed to be 100 000 μg/g; inhaled air (8-hour shift) assumed to be 10 μg/m^3 or 100 μg/m^3 with 90% efficiency or respirators.
h. 1.5 packets per day.
i. One liter per day.

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Roy (1977) studied exposures during mining and grinding of lead sulfide at a mill in the Missouri lead belt. Primary smelting operations were 2.5 miles from the mill; hence the influence of the smelter was believed to be negligible. The total airborne lead levels were much greater than the concentrations of respirable lead, indicating a predominance of coarse material.

The most hazardous operations are those in which molten lead and lead alloys are brought to high temperatures, resulting in the vaporization of lead. This is because condensed lead vapor or fume has, to a substantial degree, a small (respirable) particle size range.

A measure of the potential lead exposure in smelters was obtained in a study of three typical installations in Utah (World Health Organization, 1977). Air lead concentrations near all major operations, as determined using personal monitors worn by workers, were found to vary from about 100 to more than 4000 $\mu g/m^3$. Maximum airborne lead concentrations of about 300 $\mu g/m^3$ were measured in a primary lead-zinc smelter in the United Kingdom (King et al., 1979).

Spivey et al. (1979) studied a secondary smelter in southern California which recovers lead mainly from automotive storage batteries. Airborne lead concentrations of 10–4800 $\mu g/m^3$ were measured. In a second article covering this same study, Brown et al. (1980) reported that smokers working at a smelter had greater blood lead levels than nonsmokers. Furthermore, smokers who brought their cigarettes into the workplace had greater blood lead levels than those who left their cigarettes elsewhere. It was concluded that direct environmental contamination of the cigarettes by lead-containing dust may be a major exposure pathway for these individuals.

Secondary lead smelters in Memphis. Tennessee. and Salt Lake City, Utah, were studied by Baker et al. (1979). The former plant extracted lead principally from automotive batteries. producing 11 500 metric tons of lead in the 11 months preceding the measurements. The latter plant used scrap to recover 258 metric tons of lead in the 6 months preceding the measurements. Airborne concentrations of lead in the Tennessee study exceeded 200 $\mu g/m^3$ in some instances. with personal air sampler data ranging from 120 $\mu g/m^3$ for a battery wrecker to 350 $\mu g/m^3$ for two yard workers. At the Utah plant, airborne lead levels in the office. lunchroom and furnace room (furnace not operating) were 60, 90 and 100 $\mu g/m^3$, respectively. When charging the furnace. the last value increased to 2650 $\mu g/m^3$. Personal samplers yielded concentrations of 17 $\mu g/m^3$ for an office worker. 700 $\mu g/m^3$ for two welders. and 2660 $\mu g/m^3$ for two furnace workers.

High levels of atmospheric lead are also found in foundries in which molten lead is alloyed with other metals. Berg and Zenz (1967) found in one such operation that average concentrations of lead in various work areas were 280 and 600 $\mu g/m^3$. These levels were subsequently reduced to 30–40 $\mu g/m^3$ with the installation of forced ventilation systems to exhaust the work area atmosphere to the outside.

When metals that contain lead or are protected with a lead-containing coating are heated in the process of welding or cutting, copious quantities of lead in the respirable size range may be emitted. Under conditions of poor ventilation, electric arc welding of zinc-silicate-coated steel (containing 4.5 mg Pb/cm^2 of coating) produced breathing-zone concentrations of lead reaching 15 000 μg/m^3, far in excess of 450 μg/m^3, which is the current occupational short-term exposure limit (STEL) in the United States (Pegues, 1960). Under good ventilation conditions, a concentration of 140 μg/m^3 was measured (Tabershaw et al., 1943).

In a study of salvage workers using oxyacetylene cutting torches on lead-painted structural steel under conditions of good ventilation, breathing-zone concentrations of lead averaged 1200 μg/m^3 and ranged as high as 2400 μg/m^3 (Rieke, 1969). Lead poisoning in workers dismantling a painted bridge has been reported by Graben et al. (1978). Fischbein et al. (1978) discuss the exposure of workers dismantling an elevated subway line in New York City, where the lead content of the paint is as great as 40%. The authors report that 1 m^3 of air can contain 0.05 g lead at the source of emission. Similarly, Grandjean and Kon (1981) report elevated lead exposures of welders and other employees in a Baltimore, Maryland shipyard.

At all stages in battery manufacture, except for final assembly and finishing, workers are exposed to high air lead concentrations, particularly lead oxide dust. For example, Boscolo et al. (1978) report air lead concentrations of 16–100 μg/m^3 in a battery factory in Italy, while values up to 1315 μg/m^3 have been measured by Richter et al. (1979) in an Israeli battery factory. Excessive concentrations, as great as 5400 μg/m^3, have been reported by the World Health Organization (1977).

Workers involved in the manufacture of alkyl lead compounds are exposed to both inorganic and alkyl lead. The major potential hazard in the manufacture of tetraethyl lead and tetramethyl lead is from skin absorption, which is minimized by the use of protective clothing. Linch et al. (1970) found a correlation between an index of organic plus inorganic lead concentrations in a plant and the rate of lead excretion in the urine of workers. Cope et al. (1979) used personal air samplers to assess exposures of five alkyl lead workers exposed primarily to tetraethyl lead. Blood and urine levels were measured over a 6-week period. Alkyl lead levels in air ranged from 1.3 to 1249 μg/m^3, while inorganic lead varied from 1.3 to 62.6 μg/m^3. There was no significant correlation between airborne lead (either alkyl or inorganic) and blood or urine levels. The authors concluded that biological monitoring of blood and urine, rather than airborne lead monitoring, is a more reliable indicator of potential exposure.

In both the rubber products industry and the plastics industry there are potentially high exposures to lead. The potential hazard of the use of lead stearate as a stabilizer in the manufacture of polyvinyl chloride was noted in the 1971 Annual Report of the British Chief Inspector of Factories (United Kingdom Department of Employment, Chief Inspector of Factories, 1972). The inspector stated that the number of reported cases of

lead poisoning in the plastics industry was second only to that in the lead smelting industry. Scarlato et al. (1969) reported other individual cases of exposure. The source of this problem is the dust that is generated when the lead stearate is milled and mixed with the polyvinyl chloride and the plasticizer. An encapsulated stabilizer which greatly reduces the occupational hazard is reported by Fischbein et al. (1982).

The manufacture of cans with leaded seams may expose workers to elevated ambient lead levels. Bishop (1980) reports airborne lead concentrations of 25–800 $\mu g/m^3$ in several can manufacturing plants in the United Kingdom. Between 23 and 54% of the airborne lead was associated with respirable particles, based on cyclone sampler data.

Firing ranges may be characterized by high airborne lead concentrations. For example, Smith (1976) reports airborne lead concentrations of 30–160 $\mu g/m^3$ at a firing range in the United Kingdom. Anderson et al. (1977) discuss lead poisoning in a 17-year-old male employee of a New York City firing range, where airborne lead concentrations as high as 1000 $\mu g/m^3$ were measured during sweeping operations. Another report from the same research group presents time-weighted average exposures of instructors of 45–900 $\mu g/m^3$ in three New York City firing ranges (Fischbein et al., 1979).

Removal of leaded paint from walls and other surfaces in old houses may pose a health hazard. Feldman (1978) reports an airborne lead concentration of 510 $\mu g/m^3$ after 22 min of sanding an outdoor post coated with paint containing 2.5 mg Pb/cm^2. After only 5 min of sanding an indoor window sill containing 0.8–0.9 mg Pb/cm^2, the air contained 550 $\mu g/m^3$. Homeowners who attempt to remove leaded paint themselves may be at risk of excessive lead exposure. Garage mechanics may be exposed to excessive lead concentrations. Clausen and Rastogi (1977) report airborne lead levels of 0.2–35.5 $\mu g/m^3$ in 10 garages in Denmark: the greatest concentration was measured in a paint workshop. Used motor oils were found to contain 1500–3500 μg Pb/g, while one brand of unused gear oil contained 9280 μg Pb/g. The authors state that absorption through damaged skin could be an important exposure pathway. Other occupations involving risk of lead exposure include stained glass manufacturing and repair, arts and crafts, and soldering and splicing.

Lead is also present in tobacco. The World Health Organization (1977) estimates a lead content of 2.5–12.2 μg/cigarette: roughly 2–6% of this lead may be inhaled by the smoker. A typical urban resident who smokes 30 cigarettes/day may inhale roughly equal amounts of lead from smoking and from breathing urban air.

Reports of lead in European wines (Zurlo and Graffini, 1973; Boudene et al., 1975; Olsen et al., 1981) show concentrations averaging 100–200 μg/l and ranging as high as 300 μg/l. Measurements of lead in domestic wines were in the range of 100–300 μg/l for Californian wines with and without lead foil caps. The U.S. Food and Drug Administration (1983) found 30 μg/l in the 1982 Market Basket Survey. The average consumption of table wine by the 25 to 30-year-old adult in the United States is about 12 g/day. Even with a lead content of 0.1 $\mu g/g$, which is ten times higher than drinking water, wine does not

appear to represent a significant potential exposure to lead, based on average United States consumption data. For that segment of the population that drinks one liter per day, lead consumption would be greater than the total baseline consumption.

McDonald (1981) points out that older wines with lead foil caps may represent a hazard, especially if they have been damaged or corroded. Wai et al. (1979) found that the lead content of wine rose from 200 to 1200 μg/l when the wine was allowed to pass over the thin ring of residue left by the corroded lead foil cap. Newer wines (1971 and later) use other means of sealing. If a lead foil is used, the foil is tin-plated and coated with an acid-resistant substance. Lead levels in beer are generally smaller than those in wine; Thalacker (1980) reports a maximum concentration of 80 μg/l in several brands of German beer. The U.S. Food and Drug Administration (1983) found 13 μg/l in beer consumed by Americans.

Pica is the compulsive, habitual consumption of nonfood items, such as paint chips and soil. This habit can present a significant lead exposure to the afflicted person, especially to children, who are more likely to have pica. There are very few data on the amounts of paint or soil eaten by children with varying degrees of pica. Exposure can only be expressed on a unit basis. Billick and Gray (1978) report lead concentrations of 1000–5000 μg/cm^2 in lead-based paint pigments. A single chip of paint can represent greater exposure than any other source of lead to a child who has pica. Urban soil may contain 150–2000 μg/g.

Another potential source of dietary lead poisoning is the use of inadequately glazed earthenware vessels for food storage and cooking. An example of this danger involved the severe poisoning of a family in Idaho which resulted from drinking orange juice that had been stored in an earthenware pitcher (Block, 1969). Similar cases, sometimes including fatalities, have involved other relatively acidic beverages, such as fruit juices and soft drinks, and have been documented by other workers (Harris and Elsen, 1967: Klein et al., 1970). Because of these incidents, the U.S. Food and Drug Administration (1980) has established a maximum permissible concentration of 2.5–7 μg Pb/ml in solution after leaching with 4% acetic acid for 24 h in kitchenware, depending on the shape and volume of the vessel.

Inadequately glazed pottery manufactured in other countries continues to pose a significant health hazard. For example, Spielholtz and Kaplan (1980) report 24-hour acetic acid-leached lead concentrations as great as 4400 μg/g in Mexican pottery. The leached lead decreased with exposure time, and after several days appears to asymptotically approach 600 μg/g. These investigators have also measured excessive lead concentrations leached into acidic foods cooked for 2 h in the same pottery. Similarly, Acra et al. (1981) report that 85% of 275 earthenware vessels produced in primitive Lebanese potteries had lead levels above the 7 μg/g limit set by the U.S. FDA. However, only 9% of 75 vessels produced in a modern Beirut pottery exceeded the limit. Cubbon et al. (1981) have examined properly glazed ceramic plates in the United Kingdom, and

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have found a decrease in leached lead with exposure time down to very low levels. The authors state that earthenware satisfying the 7 μg/g limit will contribute about 3 μg/day to the dietary intake of the average consumer.

From this overview of the sources of lead exposure, both in baseline and additive circumstances, it is clear that (*a*) atmospheric lead and solder lead are the major contributors to human exposure, and (*b*) dust is an important environmental component for lead exposure in nearly every situation.

No attempt has been made in this chapter to relate these exposures to physiological parameters such as blood lead or bone lead. Consequently, it would be inappropriate to discuss the potential physiological effects of these exposure levels. Nevertheless, it would seem prudent to consider the means by which exposures to lead in the human environment can be reduced. If there is a decline, as there appears to be, in the use of solder to seal canned foods, then one would expect a gradual elimination of lead from the diets of children and adults amounting to 10–20 μg/day. This goal would be reached soon after the last lead-soldered can appears on the supermarket shelf.

Atmospheric lead, on the other hand, appears to be far more persistent in the human environment. Were emissions of airborne lead to cease immediately, some decrease in human exposure in terms of a reduction in inhaled lead would be expected to follow shortly thereafter. The atmospheric lead trapped in the upper soil layers and the lead from street and playground dusts, however, would persist for an undetermined length of time. If it is true that these atmospheric dusts and paint dust are the main components of household dust, then it is likely that this component of human lead exposure will decrease only gradually over several decades.

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